

Our Ref.: 1114-134  
61583/99R00196/US/JTH

# ***U.S. PATENT APPLICATION***

*Inventor(s):* Kazuhiko TSUDA  
Kazuhiro ISHIZUKA  
Hiroyuki OHGAMI

*Invention:* Method of Manufacturing Liquid Crystal Display Apparatus

***NIXON & VANDERHYE P.C.  
ATTORNEYS AT LAW  
1100 NORTH GLEBE ROAD  
8<sup>TH</sup> FLOOR  
ARLINGTON, VIRGINIA 22201-4714  
(703) 816-4000  
Facsimile (703) 816-4100***

## ***SPECIFICATION***

## SPECIFICATION

### TITLE OF THE INVENTION

METHOD OF MANUFACTURING LIQUID CRYSTAL DISPLAY APPARATUS

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to a method of manufacturing a liquid crystal display apparatus which carry out display by reflecting externally incident light.

#### 2. Description of the Related Art

In recent years, application of liquid crystal display apparatuses to word processors, laptop personal computers, pocket televisions and the like has rapidly been progressing. Of the liquid crystal display apparatuses, reflective-type liquid crystal display apparatuses which carry out display by reflecting externally incident light are attracting attention because the reflective-type liquid crystal display apparatuses are low in power consumption, thin and capable of being reduced in weight since no backlight is necessary.

However, in the conventional reflective-type liquid crystal display apparatuses, the brightness and the contrast of the display are dependent on the use environment such as ambient brightness or the use condition. Therefore, at present, high expectations are placed on the realization of a

reflective-type liquid crystal display apparatus that has excellent reflection characteristics, can easily be manufactured with excellent reproducibility and is high in display quality.

Japanese Unexamined Patent Publication JP-A 6-75238 (1994) discloses a technology to form random and high-density asperities on a reflecting electrode in order to improve the display quality of the reflective-type liquid crystal display apparatus.

According to this, a resin layer for adding fine asperities to a reflecting electrode comprises a first photosensitive resin layer patterned with random asperities and a second photosensitive resin layer for making the asperities smoother, and in a mask for patterning the first photosensitive resin layer, circular light intercepting portions are randomly disposed and the total area of the light intercepting portions is not less than 40% of the area of the reflecting plate.

By increasing the randomness as described above, the interference due to the repetitive pattern is prevented and the reflecting light is prevented from being colored, and by increasing the density of the asperities, the area of the flat part is reduced to thereby reduce the regular reflection component.

*SJ* Moreover, Japanese Unexamined Patent Publication JP-A 9-90426 (1997) discloses a technology to simultaneously

expose an asperity forming pattern and contact holes using only one layer of a positive photosensitive resin in order to reduce the process of manufacturing a reflective-type liquid crystal display apparatus.

A method of manufacturing a reflective-type liquid crystal display apparatus described in this patent publication will briefly be described with reference to the drawings.

Fig. 22 is a cross-sectional view showing the structure of a reflective-type liquid crystal display apparatus formed by the manufacturing method described in the above-mentioned patent publication. Figs. 23A to 23E are cross-sectional views showing the flow of the manufacturing process.

As shown in Fig. 22, in the reflective-type liquid crystal display apparatus described in the above-mentioned patent publication, a substrate in which a liquid crystal driving device 124 is formed is used as a reflecting substrate 123, and the following are provided: an aluminum pixel electrode 110 disposed on the reflecting substrate 123; a transparent electrode 112 opposed thereto; a color filter substrate 125 supporting the transparent electrode 112; liquid crystal 111 sandwiched therebetween; a phase difference plate 115 disposed above the color filter substrate 125 (on the side of the surface not opposed to the liquid crystal); and a polarizing plate 116 disposed above the phase difference plate 115.

In the reflecting substrate 123, an amorphous silicon

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transistor is formed on a glass substrate 101 as the liquid crystal driving device 124. As shown in Fig. 22, the liquid crystal driving device 124 comprises Ta as a gate electrode 102 on the glass substrate 101, SiNx as a gate insulating layer 103, a-Si as a semiconductor layer 104, n-type a-Si as an n-type semiconductor layer 105, Ti as a source electrode 107, and Ti as a drain electrode 108. In the color filter substrate 125, a color filter 113 is formed on a glass substrate 114.

A method of manufacturing the reflecting substrate 123 of the reflective-type liquid crystal display apparatus described in the above-mentioned patent publication will be described with reference to Figs. 23A to 23E.

First, as shown in Fig. 23A, a positive photosensitive resin 109 is applied to the substrate 101.

Then, as shown in Fig. 23B, exposure is carried out at high illuminance using a photomask 121 having contact hole portions 130 as light transmitting portions and in addition thereto, light transmitting portions 118 at asperity formed portions, as shown in Fig. 24. All regions except the light transmitting portions 118 of the photomask 121 are light intercepting portion 117. In the case where light 122 is applied through the photomask 121 to the photosensitive resin 109, the light passes only through the light transmitting portions 118. In the plan view of Fig. 24, the light intercepting portion 117 is hatched.

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Then, as shown in Fig. 23C, by development with a developing solution, the resin in the exposed parts mentioned above is completely removed, so that a resin configuration that is positive with respect to the mask pattern is formed.

Then, as shown in Fig. 23D, by a heat treatment, the resin in the exposed regions is deformed into smooth asperities. However, at this time the exposed regions are flat because the resin has completely been removed by the above-described developing step.

Then, as shown in Fig. 23E, an Al thin film is formed as the reflecting electrode 110, and patterning is performed so that one reflecting electrode 110 corresponds to one transistor.

The reflecting electrode 110 of the reflective-type liquid crystal display apparatus described in the above-mentioned patent publication is formed by the above-described process. In such a reflecting substrate 123, since the asperities are formed with the positive photosensitive resin in the exposed portions having been completely removed, the area of the flat part is large. In such a reflecting plate in which the area of the flat part is large, since the light source is projected in the flat region, the regular reflection component is large. Since display is difficult to confirm when the light source is projected, the regular reflection component generally is avoided in the case of the reflective-type display apparatus.

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Therefore, the regular reflection component of the reflecting plate in the reflective-type liquid crystal display apparatus disclosed in the above-mentioned patent publication do not contribute to the brightness, which results in dark display.

Compared to the reflective-type liquid crystal display apparatus disclosed in JP-A 9-90426, previously-mentioned JP-A 6-75238 discloses a reflective-type liquid crystal display apparatus adopting a complicated asperity forming process in order to create an ideal scattering condition by improving the density of the asperities of the reflecting plate. According to this apparatus, after application of a first positive photosensitive resin, first exposure development of a sufficient intensity is performed. Then, after the patterning of the asperities are completely performed, the clearances of the asperities are completely filled so that the asperities are smooth. Then, a second positive photosensitive resin is applied in order to reduce the area of the flat part, and thereafter, only the patterning of the contact hole portions is again performed by performing second exposure development.

However, in this process, since the photosensitive resin is applied in two layers, it is necessary to perform the photoprocess (application - exposure - development - heat treatment) of the photosensitive resin twice, so that the cost clearly increases.

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Further, in the reflective-type liquid crystal display apparatus disclosed in JP-A 9-90426, since one layer of a positive photosensitive resin is used, it is necessary to perform the photoprocess of the photosensitive resin only once, so that the process is simplified and cost reduction can be achieved. However, since it is necessary to ensure the removal of the photosensitive resin in the contact hole portions, it is inevitable that the positive photosensitive resin in the exposed area in the asperity forming pattern portion is also removed. Consequently, the exposed area is flat, so that in the reflecting plate, the density of the asperities is low and the regular reflection component is large.

When dust or the like exists in the regions to be exposed for removing the photosensitive resin, the resin in the parts that are left unexposed cannot be removed by development. As a result, faulty electrical continuity occurs at contact holes and a signal input terminal portion.

#### SUMMARY OF THE INVENTION

The invention is made to solve the above-mentioned problems of the reflective-type liquid crystal display apparatus, and an object thereof is to provide a method of manufacturing a reflective-type liquid crystal display apparatus with which a liquid crystal display apparatus in which faulty electric continuity does not readily occur and that has

excellent reflection characteristics can easily be manufactured with excellent reproducibility and the display quality improves.

The invention provides a method of manufacturing a liquid crystal display apparatus having, on one of a pair of substrates disposed so as to be opposed with a liquid crystal layer therebetween, reflecting means for reflecting incident light from the other substrate, comprising the steps of:

applying a photosensitive resin on one of the substrate;  
forming asperities in a first region of the applied photosensitive resin film by exposing the first region with various integrals of exposure amount so that the photosensitive resin in the first region is left in different film thicknesses, and forming in a second region of the applied photosensitive resin film a concave portion so that the photosensitive resin in the second region is left in a thickness smaller than those of the first region by exposing the second region with an integral of exposure amount different from those for the first region;

developing the exposed photosensitive resin;  
heat-treating the developed photosensitive resin; and  
forming a reflecting film on the heat-treated photosensitive resin.

According to the invention, by exposing the regions of different patterns of the photosensitive resin applied to the

substrate with different integrals of exposure amount on an area basis, a smooth region having high-density asperities and other regions having no high-density asperities can be formed with a reduced number of steps.

That is, there are hardly any flat parts in the asperities formed region because the asperities formed region can be formed into a curved surface by a heat treatment under a condition that there is no part in which the photosensitive resin is completely removed. Consequently, excellent reflection characteristics with a reduced regular reflection component can be realized.

At the exposing step, since the negative photosensitive resin in the part intercepted from light by a photomask (light intercepted region) is readily soluble in a developing solution, circular or polygonal pillars or holes are formed, and since the negative photosensitive resin in the part not intercepted from light by the photomask (light transmitting region) is not readily soluble in the developing solution, a photosensitive resin film having asperities is formed on the substrate in correspondence with the light transmitting region and the light intercepted region of the photomask by developing the photosensitive resin with the developing solution after the exposure.

Moreover, at the exposing step, since the positive photosensitive resin in the part intercepted from light by a photomask (light intercepted region) is not readily soluble in

a developing solution, circular or polygonal pillars or holes are formed, and since the positive photosensitive resin in the part not intercepted from light by the photomask (light transmitting region) is readily soluble in the developing solution, a photosensitive resin film having asperities is formed on the substrate in correspondence with the light transmitting region and the light intercepted region of the photomask by developing the photosensitive resin film with the developing solution after the exposure.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that a reflecting electrode comprising the reflecting film is formed in the first region of the photosensitive resin film and that the reflecting electrode is connected to wiring formed in a lower layer of the reflecting electrode in the second region of the photosensitive resin film.

According to the invention, owing to the use of the photosensitive resin as an interlayer insulating film, the reflecting electrode can be manufactured by a minimum number of steps. By forming the reflecting electrode in the first region of the photosensitive resin film and connecting the reflecting electrode to the wiring formed in the lower layer of the reflecting electrode in the second region of the photosensitive resin film, that is, removing the resin in regions corresponding to contact holes for connecting the

reflecting electrode and a liquid crystal driving device, the photosensitive resin is left over the entire display picture element region except the contact holes, so that asperities in which the area of the flat part is small and which is smooth over the entire picture element region can be formed. As a result, bright reflected light with reduced regular reflection can be obtained.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that a terminal portion is formed in an outside display region on one of the substrates and that the second region of the photosensitive resin film is formed in the terminal portion.

According to the invention, owing to the use of the photosensitive resin as an interlayer insulating film and the formation of a light transmitting region corresponding to the terminal portion for inputting an external signal in the second region of the photosensitive resin, the terminal portion can be manufactured by a minimum number of steps.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that the photosensitive resin is negative, and that the step of exposing the photosensitive resin includes a step of exposing the photosensitive resin using a photomask having a light transmitting portion, a light intercepting portion and a semi-light transmitting portion, to form the first region in

regions corresponding to the light transmitting portion and semi-light transmitting portion of the photomask, and the second region in a region corresponding to the light intercepting portion of the photomask.

According to the invention, since the step of exposing the photosensitive resin includes the step of exposing the photosensitive resin using the photomask having the light transmitting portion, the light intercepting portion and the semi-light transmitting portion, to form the first region in the regions corresponding to the light transmitting portion and semi-light transmitting portion of the photomask and the second region in the region corresponding to the light intercepting portion of the photomask, the number of exposures can be reduced to one.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that the photosensitive resin is positive, and that the step of exposing the photosensitive resin includes a step of exposing the photosensitive resin using a photomask having a light transmitting portion, a light intercepting portion and a semi-light transmitting portion, to form the first region in regions corresponding to the light intercepting portion and semi-light transmitting portion of the photomask, and the second region in a region corresponding to the light transmitting portion of the photomask.

According to the invention, since the step of exposing the photosensitive resin includes the step of exposing the photosensitive resin using the photomask having the light transmitting portion, the light intercepting portion and the semi-light transmitting portion, to form the first region in the regions corresponding to the light intercepting portion and semi-light transmitting portion of the photomask and the second region in the region corresponding to the light transmitting portion of the photomask, the number of exposures can be reduced to one.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that the step of exposing the photosensitive resin includes a step of exposing the photosensitive resin using a first photomask and a step of exposing the photosensitive resin using a second photomask, to form the first region and the second region with the first and second photomasks, respectively.

According to the invention, since the step of exposing the photosensitive resin includes the step of exposing the photosensitive resin using the first photomask and the step of exposing the photosensitive resin using the second photomask, to form the first and second regions by the first and second photomasks, it is made possible to use photomasks composed of only a light transmitting portion and a light intercepting portion, with the result that the design and manufacture of the

photomasks is facilitated and the number of exposing steps can be reduced.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that the exposure amount at the step of exposing the photosensitive resin using the first photomask and the exposure amount at the step of exposing the photosensitive resin using the second photomask are the same.

According to the invention, since the exposure with the first photomask and the exposure with the second photomask are carried out in the same exposure amount, the light quantity adjustment is facilitated, with the result that the throughput of the exposing step can be enhanced.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that uniform and low-illuminance exposure is performed at the step of exposing the photosensitive resin using the first photomask, while uniform and high-illuminance exposure is performed at the step of exposing the photosensitive resin using the second photomask.

According to the invention, in the case where negative photosensitive resin is used, since uniform and low-illuminance exposure is performed at the step of exposing the photosensitive resin using the first photomask and uniform and high-illuminance exposure is performed at the step of exposing the

negative photoresist formation

photosensitive resin using the second photomask, it becomes possible to expose only a convex formed region in the first region at a high illuminance, so that it is possible that the photosensitive resin is completely left in the first region with more reliability. Here, the high-illuminance exposure indicates an exposure of such an extent of exposure amount that cross-linking of the resin sufficiently progresses in the negative photosensitive resin and the left film amount after the development is larger than substantially 50% of the film thickness before the development, and the low-illuminance exposure indicates an exposure of such an extent of exposure amount that cross-linking of the resin does not sufficiently progress in the negative photosensitive resin and the left film amount after the development is 0% or more and less than 50%, preferably, 10% or more and less than 50% of the film thickness before the development.

More specifically, in the negative photosensitive resin formed on the substrate, owing to the low-illuminance exposure with the first photomask, cross-linking of the photosensitive resin in the part subjected to the low-illuminance exposure with the first photomask does not sufficiently progress, so that the film of the photosensitive resin in the part subjected to the low-illuminance exposure is uniformly reduced in thickness by the development with a development solution after the exposure.

Moreover, in the negative photosensitive resin formed

on the substrate, by performing the high-illuminance exposure using the second photomask, cross-linking of the photosensitive resin in the part exposed at a high illuminance using the second photomask sufficiently progresses, so that a convex portion being higher by one step than the unexposed part by the second photomask is formed by the development with the developing solution after the exposure and it is possible to form smooth asperities by the resin being deformed in a succeeding heat treatment.

As described above, by performing the high-illuminance exposure, the low-illuminance exposure and development on one layer of negative photosensitive resin and then, heat-treating the photosensitive resin, the asperities of the photosensitive resin formed on the substrate are deformed, so that continuous, high-density and smooth asperities without any flat part are formed on the substrate.

In the case where positive photosensitive resin is used, by performing the uniform and low-illuminance exposure at the step of exposing the photosensitive resin using the first photomask and performing the uniform and high-illuminance exposure at the step of exposing the photosensitive resin using the second photomask, it becomes possible that only the second region is exposed at a high illuminance independently of an optimum exposure condition for the first region, so that it is possible to completely remove the photosensitive resin with

more reliability in the first region. Here, the high-illuminance exposure indicates an exposure performed with an exposure amount where a sensitizer that restrains the dissolution of the resin in the developing solution is made sufficiently soluble in the positive photosensitive resin and the left film amount after the development is substantially 0%, and the low-illuminance exposure indicates an exposure performed with an exposure amount where the solubilization of the sensitizer that restrains the dissolution of the resin in the developing solution is not sufficiently performed in the positive photosensitive resin and the left film amount after the development is 0% or more and less than 50%, preferably, not in a range of from 10% to 50% of the film thickness before the development.

More specifically, in the positive photosensitive resin formed on the substrate, owing to the low-illuminance exposure with the first photomask, the sensitizer in the part subjected to the exposure of a low illuminance with the first photomask is not sufficiently solubilized, so that the film of the part subjected to the low-illuminance exposure is uniformly reduced in thickness by the development with the developing solution after the exposure.

Moreover, in the positive photosensitive resin formed on the substrate, owing to the high-illuminance exposure with the second photomask, the sensitizer in the part subject to the

exposure of a high illuminance using the second photomask is sufficiently solubilized, so that the photosensitive resin on the substrate is completely removed by the development with the developing solution after the exposure. This enables the connection between the reflecting electrode formed at a succeeding step and a TFT drain electrode.

As described above, owing to the high-illuminance exposure, the low-illuminance exposure and development on one layer of a positive photosensitive resin and heat-treatment of the photosensitive resin, the asperities of the photosensitive resin formed on the substrate are deformed by heat, with the result that continuous, high-density and smooth asperities without any flat part are formed on the substrate.

Further, by forming the reflecting electrode on the heat-treated photosensitive resin having the smooth asperities, excellent reflecting means with a small regular reflection component can be formed.

In the invention, the order of the steps of the low-illuminance exposure and the high-illuminance exposure, that is, the order of the first exposing step and the second exposing step may be opposite to the above-described order.

As the process from the exposing step to the developing step, the following two are considered: the process from exposure (the low-illuminance exposure and the high-illuminance exposure) to development; and the process from

exposure (the low-illuminance exposure or the high-illuminance exposure) through development and exposure (the high-illuminance exposure or the low-illuminance exposure) to development. In the invention, either of the two processes can be used. However, the former process is preferable in view of the simplification of the process.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that circular or polygonal regions are irregularly disposed in the first or second photomask and that the total area of the circular or polygonal regions is in a range of from 20% to 40% of the total area of the photomask.

According to the invention, since the circular or polygonal regions are irregularly disposed in the first or second photomask, the total area of the circular or polygonal regions is in a range of from 20% to 40% of the total area of the photomask and the circular or polygonal regions are irregularly disposed, the periodicity of the pattern of the asperities of the photosensitive resin formed on the substrate is eliminated, so that the light interference phenomenon can be prevented. As a result, white scattered light without any color can be obtained. Moreover, since the scattered light from the asperities does not biased in a specific direction, uniform scattered light can be obtained.

Since the total area of the circular or polygonal regions

in the first or second photomask is in a range of from 20% to 40% of the photomask, the angle of inclination of the asperities of the photosensitive resin formed on the substrate can be controlled so that the light can efficiently be used.

Here, the total area of the photomask concretely means the total area of the reflecting electrode. In the case where the area of the circular or polygonal regions in the first or second photomask is not less than 40%, when the circular or polygonal regions are randomly disposed, adjoining circular or polygonal regions overlap each other into a large pattern, so that the pattern density decreases as a whole and the ratio of the area of the flat part increases. As a result, a reflecting plate with a large regular reflection component is formed. In the case where the area of the circular or polygonal regions in the first or second photomask is not more than 20%, when the circular or polygonal regions are randomly disposed, the distances between adjoining circular or polygonal regions are too large, so that the distances between convex portions and convex portions or concave portions and concave portions of the configuration of the photosensitive resin formed by development are too large and flat parts are left between convex portions or concave portions when the resin is deformed by heating. As a result, a reflecting plate with a large regular reflection component is formed. From these, in the invention, the total area of the circular regions in the first or second photomask

is in a range of from 20% to 40% of the total area of the photomask.

A photomask having the above-described characteristics is selected as the second photomask when negative photosensitive resin is used, and is selected as the first photomask when a positive photosensitive resin is used.

Moreover, in the method of manufacturing a liquid crystal display apparatus according to the invention, it is preferable that the circular or polygonal regions disposed in the first or second photomask are irregularly disposed so that the center-to-center distances between adjoining regions are in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ .

According to the invention, by irregularly disposing the circular or polygonal regions disposed in the first or second photomask so that the center-to-center distances between adjoining regions are in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , a sufficient number of asperity patterns can be disposed for one picture element of the liquid crystal display apparatus, so that scattered light can be obtained in which there is no difference in characteristics between picture elements.

In the case where adjoining circular or polygonal regions are disposed so as not to overlap each other, patterns in which the center-to-center distance is not more than 5  $\mu\text{m}$  are not resolved but become flat because of the limit of resolution of the stepper, so that a reflecting plate with a large regular reflection component is formed. Generally, in a liquid crystal

display apparatus, since the size of one picture element is not more than approximately  $100 \mu\text{m} \times 300 \mu\text{m}$ , to dispose approximately ten or more convex portions or concave portions for one picture element in order to obtain uniform scattering property, it is necessary that the center-to-center distance is substantially not more than  $50 \mu\text{m}$ . When the center-to-center distance is larger than  $50 \mu\text{m}$ , since the distances between the circular regions are large, the ratio of the area of the flat part increases, so that a reflecting plate with a large regular reflection component is formed. From these, in the invention, the circular or polygonal regions disposed in the first or second photomask are irregularly disposed so that the center-to-center distances between adjoining circular or polygonal regions are in a range of from  $5 \mu\text{m}$  to  $50 \mu\text{m}$ .

According to the invention, by exposing one layer of a photosensitive resin applied to the substrate with the different integrals of exposure amount on an area basis, smooth and high-density asperities can be formed, so that ideal reflecting means with a reduced flat area and a small regular reflection component can be formed. Consequently, the number of photoprocesses of the photosensitive resin can be reduced to thereby reduce the cost necessary for the manufacture.

In the invention, since a negative photosensitive resin is used, the resin in a part that is not exposed because of the presence of dust or the like can be removed by development, so

that electric continuity is ensured even when dust or the like adheres to the contact hole portions and the signal input terminal portion.

In the invention, since a positive photosensitive resin is used, when the low-illuminance exposure is performed with the photomask, the reaction progresses from the surface of the photosensitive resin, so that dissolution readily progresses from the surface when the reacting portion is dissolved by the development, and in the case where it is necessary to control the film reduction amount like in the invention, the control can easily be performed while the adhesion to the substrate is maintained.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other and further objects, features, and advantages of the invention will be more explicit from the following detailed description taken with reference to the drawings wherein:

Fig. 1 is a plan view of a reflecting substrate 23 used in a reflective-type liquid crystal display apparatus according to Embodiment 1 of the invention;

Fig. 2 is a cross-sectional view of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 1 of the invention;

Figs. 3A to 3K are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in

the reflective-type liquid crystal display apparatus according to Embodiment 1 of the invention;

Fig. 4 is a schematic plan view showing the patterns of a light transmitting portion 17a and light intercepting portions 18a of a first photomask 19 according to Embodiment 1 of the invention;

Fig. 5 is a schematic plan view showing the patterns of light transmitting portions 17b and a light intercepting portion 18b of a second photomask 20 according to Embodiment 1 of the invention;

Figs. 6A to 6J are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in a reflective-type liquid crystal display apparatus according to Embodiment 2 of the invention;

Fig. 7 is a schematic plan view showing the pattern of a photomask 35 according to Embodiment 2 of the invention;

Figs. 8A to 8K are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 3 of the invention;

Figs. 9A to 9K are cross-sectional views showing a manufacturing process of a reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 4 of the invention;

Fig. 10 is a schematic plan view showing the patterns

of a light transmitting portion 41a and light intercepting portions 42a of a first photomask 43 according to Embodiment 4 of the invention;

Fig. 11 is a schematic plan view showing the patterns of light transmitting portions 41b and a light intercepting portion 42b of a second photomask 44 according to Embodiment 4 of the invention;

Figs. 12A to 12J are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 5 of the invention;

Fig. 13 is a schematic plan view showing the pattern of a photomask 47 according to Embodiment 5 of the invention;

Figs. 14A to 14L are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in a reflective-type liquid crystal display apparatus according to Embodiment 6 of the invention;

Fig. 15 is a plan view of a reflecting substrate 49 used in a transmissive/reflective type liquid crystal display apparatus according to Embodiment 7 of the invention;

Fig. 16 is a cross-sectional view of the reflecting substrate 49 used in the transmissive/reflective type liquid crystal display apparatus according to Embodiment 7 of the invention;

Figs. 17A to 17F are cross-sectional views showing a

manufacturing process of the reflecting substrate 49 used in the transmissive/reflective type liquid crystal display apparatus according to Embodiment 7 of the invention;

Fig. 18 is a schematic plan view showing the patterns of a light transmitting portion 52a and light intercepting portions 53a and 53b of a first photomask 51 according to Embodiment 7 of the invention;

Fig. 19 is a schematic plan view showing the patterns of light transmitting portions 52c and a light intercepting portion 53c of a second photomask 54 according to Embodiment 7 of the invention;

Figs. 20A to 20F are cross-sectional views showing a manufacturing process of the reflecting substrate 49 used in a transmissive/reflective type liquid crystal display apparatus according to Embodiment 8 of the invention;

Fig. 21 is a schematic plan view showing the patterns of light transmitting portions 52d and 52e and a light intercepting portion 53d of a second photomask 55 according to Embodiment 8 of the invention;

Fig. 22 is a cross-sectional view showing the reflective-type liquid crystal display apparatus formed by the conventional manufacturing method;

Figs. 23A to 23E are cross-sectional views showing the manufacturing process of the reflecting substrate 123 in the conventional reflective-type liquid crystal display apparatus;

and

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Fig. 24 is a schematic plan view showing the patterns of the light transmitting portions 118 and the light intercepting portion 117 of the conventional photomask 121.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now referring to the drawings, preferred embodiments of the invention are described below.

##### (Embodiment 1)

Fig. 1 is a plan view showing a reflecting substrate 23 of a reflective-type liquid crystal display apparatus according to Embodiment 1. Fig. 2 is a cross-sectional view of the reflecting substrate 23 shown in Fig. 1. Figs. 3A to 3K are cross-sectional views showing the flow of the manufacturing process of the substrate 23.

As shown in Figs. 1 and 2, on the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to this embodiment, a reflecting electrode 10 is formed, and the surface thereof has smooth asperities comprising circular concave or convex portions 33. On a glass substrate 1, an amorphous silicon transistor is formed as a liquid crystal driving device 24. The liquid crystal driving device 24 comprises Ta as a gate electrode 2 on the glass substrate 1, SiNx as a gate insulating layer 3, a-Si as a semiconductor layer 4, n-type a-Si as an n-type semiconductor

layer 5, Ti as a source electrode 7, and Ti as a drain electrode 8.

A signal input terminal portion 27 for inputting signals to a gate bus line and a source bus line comprises a terminal portion electrode 2 of Ta and a terminal connection electrode 26 of ITO formed by patterning simultaneously with the gate bus line and the gate electrode.

A manufacturing process of the reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment will be described with reference to Figs. 3A to 3K. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 3A, a negative photosensitive resin 9 (the name of the product: FE301N manufactured by Fuji Film Olin) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using a first photomask 19 in which light intercepting portions 18a corresponding to contact hole portions 30 were disposed as shown in Fig. 4, the region other than the contact hole portions was uniformly exposed at a low illuminance as shown in Fig. 3B. In the first photomask 19, the region other than the light intercepting portions 18a is a light transmitting portion 17a. It is desirable that the

exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed with an exposure amount of 40 mj. In the plan view of Fig. 4, the light intercepting portions 18a are hatched.

Then, by using a second photomask 20 in which the area of light transmitting portions 17b was in a range of from 20% to 40% as circular regions in the region other than the contact hole portions 30 as shown in Fig. 5, the region other than the contact hole portions 30 was uniformly exposed at a high illuminance as shown in Fig. 3C. In the second photomask 20, the region other than the light transmitting portions 17b is a light intercepting portion 18b. It is desirable that the exposure amount at this time is 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj. At this time, the circular or polygonal light transmitting portions 17b of the second photomask 20 were randomly disposed so that the center-to-center distances between adjoining light transmitting portions 17b were in a range of from 5  $\mu$ m to 50  $\mu$ m, preferably, 10  $\mu$ m to 20  $\mu$ m. In the plan view of Fig. 5, the light intercepting portion 18b is hatched.

At this time, the first and the second photomasks 19 and 20 were structured so as to intercept the signal input terminal portion 27 from light as well as the contact holes.

Then, as shown in Fig. 3D, by performing development with

a developing solution TMAH (tetramethylammoniumhydrooxide) manufactured by Tokyo Ohka Kogyo Co., Ltd., the resin in the unexposed part (the contact hole portions and the signal input terminal portion) was completely removed, approximately 40%, with respect to the initial film thickness, of the resin in the part exposed at a low illuminance was left, and approximately 80%, with respect to the initial film thickness, of the resin in the part exposed at a high illuminance was left.

Then, as shown in Fig. 3E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

Then, as shown in Fig. 3F, an Al thin film was formed by sputtering as the reflecting electrode 10 on the substrate 1 in a thickness of 2000 Å, and as shown in Figs. 3G to 3K, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

Specifically, the patterning of the Al electrode serving as the reflecting electrode 10 was carried out in such a manner that: a photoresist 28 was applied as shown in Fig. 3G; a portion to be removed for separation of each pixel electrode and the signal input terminal portion 27 were exposed as shown in Fig. 3H; and development, etching and exfoliation were performed as shown in Figs. 3I to 3K.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In

such a reflecting substrate 23, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

(Embodiment 2)

Hereinafter, a reflective-type liquid crystal display apparatus according to Embodiment 2 of the invention will be described with reference to the drawings. The reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment is the same as the reflecting substrate 23 shown in Fig. 1 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 6A to 6J.

Figs. 6A to 6J are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in

the reflective-type liquid crystal display apparatus according to Embodiment 2. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 6A, the negative photosensitive resin 9 (the name of the product: FE301N manufactured by Fuji Film Olin) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, using a photomask 35 in which light transmitting portions 17c, light intercepting portions 18c and a semi-light transmitting portion 29 other than the portions 17c and 18c are mixed and the area of the light transmitting portions 17c is in a range of from 20% to 40% as circular regions as shown in Fig. 7, exposure was uniformly performed at a high illuminance as shown in Fig. 6B. It is preferable that the exposure amount at this time is in a range of from 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj. At this time, the area of the circular or polygonal light transmitting portions 17c of the photomask 35 was 30%, the light transmitting portions 17c were randomly disposed so that the center-to-center distances between adjoining light transmitting portions 17c were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ , the light intercepting portions 18c were disposed in the regions corresponding to the contact

holes 30, and the semi-light transmitting portion 29 whose light transmittance was 17% of that of the light transmitting portions 17c was disposed in the region other than the portions 17c and 18c. Although not shown, the region other than the display region is a light intercepting region. In the plan view of Fig. 7, the semi-light transmitting portion 29 and the light intercepting portions 18c are hatched.

The succeeding process is similar to that of the above-described Embodiment 1. Development was performed as shown in Fig. 6C, and a heat treatment was performed as shown in Fig. 6D, so that smooth asperities were formed by the resin being deformed.

Then, as shown in Fig. 6E, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and as shown in Figs. 6F to 6J, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In such a reflecting substrate 23, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter

substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

In the reflective-type liquid crystal display apparatus according to this embodiment, while the reflecting electrode having smooth and high-density reflecting asperities is formed like in the above-described Embodiment 1, the number of exposures can further be reduced by using the photomask having the semi-light transmitting portion in the photoprocess of the photosensitive resin, so that the cost necessary for the manufacture of the reflecting substrate 23 can be reduced.

(Embodiment 3)

Hereinafter, a reflective-type liquid crystal display apparatus according to Embodiment 3 of the invention will be described with reference to the drawings. The reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment is the same as the reflecting substrate 23 shown in Fig. 1 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 8A to 8K.

Figs. 8A to 8K are cross-sectional views showing a

manufacturing process of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 3. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 8A, the negative photosensitive resin 9 (the name of the product: FE301N manufactured by Fuji Film Olin) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using the second photomask 20 in which the area of the light transmitting portions 17b was in a range of from 20% to 40% as circular regions in the region other than the contact hole portions 30 as shown in Fig. 5, the region other than the contact hole portions 30 was uniformly exposed at a low illuminance as shown in Fig. 8B. It is desirable that the exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed with an exposure amount of 40 mj. At this time, the circular or polygonal light transmitting portions 17b of the second photomask 20 were randomly disposed so that the center-to-center distances between adjoining light transmitting portions 17b were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ .

Then, by using the first photomask 19 in which the light intercepting portions 18a corresponding to the contact hole

portions 30 were disposed as shown in Fig. 4, the region other than the contact hole portions 30 was uniformly exposed with an exposure amount of 40 mj which was the same as that in the above-described first exposure process as shown in Fig. 8C. The first and the second photomasks 19 and 20 were structured so as to intercept the signal input terminal portion 27 from light as well as the contact hole portions.

Then, as shown in Fig. 8D, by performing development with a developing solution TMAH (tetramethylammoniumhydrooxide) manufactured by Tokyo Ohka Kogyo Co., Ltd., the resin in the unexposed part (the contact hole portions and the signal input terminal portion) was completely removed, approximately 30%, with respect to the initial film thickness, of the resin in the part exposed once was left, and approximately 70%, with respect to the initial film thickness, of the resin in the part exposed twice was left.

Then, as shown in Fig. 8E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

The succeeding process is similar to that of the above-described Embodiments 1 and 2. As shown in Fig. 8F, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and as shown in Figs. 8J to 8K, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In such a reflecting substrate 23, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

In the reflective-type liquid crystal display apparatus according to this embodiment, while the reflecting electrode having smooth and high-density reflecting asperities is formed like in the above-described Embodiment 1, the throughput of the apparatus improves by performing the first and the second exposures with the same exposure amount in the photoprocess of the photosensitive resin, and the cost necessary for the manufacture of the reflecting substrate 23 can be reduced.

(Embodiment 4)

Hereinafter, a reflective-type liquid crystal display

apparatus according to Embodiment 4 of the invention will be described with reference to the drawings. The reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment is the same as the reflecting substrate 23 shown in Fig. 1 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 9A to 9K.

Figs. 9A to 9K are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according to Embodiment 4. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 9A, a positive photosensitive resin 9 (the name of the product: OFPR-800 manufactured by Tokyo Ohka Kogyo Co., Ltd.) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using a first photomask 43 in which the area of light intercepting portions 42a was in a range of from 20% to 40% as circular regions as shown in Fig. 10, exposure was uniformly performed at a low illuminance as shown in Fig. 9B. In the first photomask 43, the region other than the light intercepting portions 42a is a light transmitting portion 41a.

It is desirable that the exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed with an exposure amount of 40 mj. At this time, the circular or polygonal light intercepting portions 42a of the first photomask 43 were randomly disposed so that the center-to-center distances between adjoining light intercepting portions 42a were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ . In the plan view of Fig. 10, the light intercepting portions 42a are hatched.

Then, by using a second photomask 44 in which light transmitting portions 41b corresponding to the contact hole portions 30 were opened as shown in Fig. 11, the contact hole portions were uniformly exposed at a high illuminance as shown in Fig. 9C. In the second photomask 44, the region other than the light transmitting portions 41b is a light intercepting portion 42b. At this time, the second photomask 44 also serves as a light transmitting portion with respect to the signal input terminal portion 27, and the terminal portion 27 was exposed at a high illuminance simultaneously with the exposure of the contact holes. It is desirable that the exposure amount at this time is 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj. In the plan view of Fig. 11, the light intercepting portion 42b is hatched.

Then, as shown in Fig. 9D, by performing development with a developing solution TMAH (tetramethylammoniumhydrooxide)

manufactured by Tokyo Ohka Kogyo Co., Ltd., the resin in the part exposed at a high illuminance (the contact hole portions and the signal input terminal portion) was completely removed, approximately 40%, with respect to the initial film thickness, of the resin in the part exposed at a low illuminance was left, and approximately 80%, with respect to the initial film thickness, of the resin in the unexposed part was left.

Then, as shown in Fig. 9E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

Then, as shown in Fig. 9F, an Al thin film was formed by sputtering as the reflecting electrode 10 on the substrate 1 in a thickness of 2000 Å, and as shown in Figs. 9G to 9K, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

Specifically, the photoresist 28 was applied as shown in Fig. 9G, a portion to be removed for separation of each pixel electrode and the signal input terminal portion 27 were exposed as shown in Fig. 9H, and development, etching and exfoliation were performed as shown in Figs. 9I to 9K to thereby perform patterning of the Al thin film serving as the reflecting electrode 10.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In such a reflecting substrate 23, the area of the flat part is

reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

(Embodiment 5)

Hereinafter, a reflective-type liquid crystal display apparatus according to Embodiment 5 of the invention will be described with reference to the drawings. The reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment is the same as the reflecting substrate 23 shown in Fig. 1 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 12A to 12J.

Figs. 12A to 12J are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in the reflective-type liquid crystal display apparatus according

to Embodiment 5. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 12A, the positive photosensitive resin 9 (the name of the product: OFPR-800 manufactured by Tokyo Ohka Kogyo Co., Ltd.) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using a photomask 47 in which light intercepting portions 42c, light transmitting portions 41c and a semi-light transmitting portion 46 coexisted and the area of the light intercepting portions 42c was in a range of from 20% to 40% as circular regions as shown in Fig. 13, exposure was uniformly performed at a high illuminance as shown in Fig. 12B. It is desirable that the exposure amount at this time is 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj. At this time, the area of the circular or polygonal light intercepting portions 42c of the photomask 47 was 30%, the light intercepting portions 42c were randomly disposed so that the center-to-center distances between adjoining light intercepting portions 42c were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ , the light transmitting portions 41c were disposed in the regions corresponding to the contact holes 30, and the semi-light transmitting portion 46 whose light transmittance was 17% of

that of the light transmitting portions was disposed in the region other than the portions 41c and 42c. Although not shown, the region other than the display region is a light transmitting region. In the plan view of Fig. 13, the semi-light transmitting portion 46 and the light intercepting portions 42c are hatched.

The succeeding process is similar to that of the above-described Embodiment 4. Development was performed as shown in Fig. 12C, and a heat treatment was performed as shown in Fig. 12D, so that smooth asperities were formed by the resin deformed.

Then, as shown in Fig. 12E, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and as shown in Figs. 12F to 12J, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In such a reflecting substrate 23, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter substrate for supporting a transparent electrode are bonded

together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

In the reflective-type liquid crystal display apparatus according to this embodiment, while the reflecting electrode having smooth and high-density asperities is formed like in the above-described Embodiment 1, the number of exposures can further be reduced by using the photomask having the semi-light transmitting portions in the photoprocess of the photosensitive resin, and the cost necessary for the manufacture of the reflecting substrate 23 can be reduced.

(Embodiment 6)

Hereinafter, a reflective-type liquid crystal display apparatus according to Embodiment 6 of the invention will be described with reference to the drawings. The reflecting substrate 23 of the reflective-type liquid crystal display apparatus according to this embodiment is the same as the reflecting substrate 23 shown in Fig. 1 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 14A to 14L.

Figs. 14A to 14L are cross-sectional views showing a manufacturing process of the reflecting substrate 23 used in

the reflective-type liquid crystal display apparatus according to Embodiment 6. In these figures, the pixel region is shown on the left side, and the signal input terminal portion region is shown on the right side.

First, as shown in Fig. 14A, the positive photosensitive resin 9 (the name of the product: OFPR-800 manufactured by Tokyo Ohka Kogyo Co., Ltd.) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using the first photomask 43 so that the area of the light intercepting portions 42a was in a range of from 20% to 40% as circular regions as shown in Fig. 10, exposure was uniformly performed at a low illuminance as shown in Fig. 14B. It is desirable that the exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed with an exposure amount of 40 mj. At this time, the circular or polygonal light intercepting portions 42a of the first photomask 43 were randomly disposed so that the center-to-center distances between adjoining light intercepting portions 42a were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ .

Then, by using the second photomask 44 in which the light transmitting portions 41b corresponding to the contact hole portions 30 were opened as shown in Fig. 11, the contact hole portions were uniformly exposed with an exposure amount of 40

μm which was the same as that in the above-described first exposure process as shown in Fig. 14C.

Then, as shown in Fig. 14D, by performing development with a developing solution TMAH

(tetramethylammoniumhydroxide) manufactured by Tokyo Ohka Kogyo Co., Ltd., approximately 2% (0.06 μm) of the resin in the part exposed twice (the contact hole portions and the signal input terminal portion) was left, approximately 40%, with respect to the initial film thickness, of the resin in the part exposed once was left, and approximately 80%, with respect to the initial film thickness, of the resin in the unexposed part was left.

Then, as shown in Fig. 14E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

Then, as shown in Fig. 14F, by exposing the substrate to an oxygen plasma atmosphere for five minutes in a dry etching apparatus, the outermost surface of the photosensitive resin was etched to be reduced in thickness by 0.1 μm as a whole, so that the resin in the contact hole portions and the signal input terminal portion was completely removed. This process was performed because approximately 2% of the photosensitive resin was left in the contact hole portions. However, this process is unnecessary when the resin is completely removed after the development.

The succeeding process is similar to that of the above-described Embodiments 1 to 5. As shown in Fig. 14G, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and as shown in Figs. 14H to 14L, patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the reflecting electrode 10 having smooth and high-density asperities was formed. In such a reflecting substrate 23, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the reflecting substrate 23 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the reflective-type liquid crystal display apparatus according to this embodiment.

In the reflective-type liquid crystal display apparatus according to this embodiment, while the reflecting electrode having smooth and high-density asperities is formed like in the above-described Embodiment 1, the throughput of the apparatus

is enhanced by performing the first and the second exposures with the same exposure amount in the photoprocess of the photosensitive resin, and the cost necessary for the manufacture of the reflecting substrate 23 can be reduced.

(Embodiment 7)

Hereinafter, a transmissive/reflective type liquid crystal display apparatus according to Embodiment 7 of the invention will be described with reference to the drawings. Fig. 15 is a plan view showing a substrate 49 of the transmissive/reflective type liquid crystal display apparatus according to this embodiment. Fig. 16 is a cross-sectional view of the substrate 49 shown in Fig. 15. Figs. 17A to 17F are cross-sectional views showing the flow of the manufacturing process of the substrate 49.

As shown in Figs. 15 and 16, in the substrate 49 used in the transmissive/reflective type liquid crystal display apparatus according to this embodiment, one pixel electrode formed on the substrate 49 is divided into a reflecting region in which the reflecting electrode 10 is formed and a transmitting region 31 in which a transparent electrode 37 is formed. The reflecting electrode 10 has on the surface thereof smooth and high-density asperities comprising the circular concave or convex portions 33 like in Embodiments 1 to 6.

With this structure, the transmissive/reflective type liquid crystal display apparatus according to this embodiment

can be used as a reflective-type liquid crystal display apparatus when the ambient light is so strong that the display is dimmed in a transmissive liquid crystal display apparatus, and can be used as a transmissive liquid crystal display apparatus by turning on the backlight when the display cannot be clearly viewed in the reflective-type liquid crystal display apparatus because of a dim environment.

In the transmissive/reflective type liquid crystal display apparatus according to this embodiment, as shown in Figs. 15 and 16, an amorphous silicon transistor is formed on the glass substrate 1 as the liquid crystal driving device 24. The liquid crystal driving device 24 comprises Ta as the gate electrode 2 on the glass substrate 1, SiNx as the gate insulating layer 3, a-Si as the semiconductor layer 4, n-type a-Si as the n-type semiconductor layer 5, the source electrode 7 and the drain electrode 8 made of ITO, and a Ta layer 32 formed on the electrodes 7 and 8. The ITO of the drain electrode 8 is extended to the pixel region to form the transparent electrode 37 formed in the transmitting region.

Although not shown in this embodiment, the signal input terminal portion 27 for inputting signals to the gate bus line and the source bus line is similar to those of the above-described Embodiments 1 to 6.

A manufacturing process of the substrate 49 of the transmissive/reflective type liquid crystal display apparatus

according to this embodiment will be described with reference to Figs. 17A to 17F. In Figs. 17A to 17F, the ITO being present in the transmitting region 31 is omitted.

First, as shown in Fig. 17A, the negative photosensitive resin 9 (the name of the product: OFPR-800 manufactured by Tokyo Ohka Kogyo Co., Ltd.) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu$ m. In this embodiment, the resin 9 was applied in a thickness of 3  $\mu$ m.

Then, by using a first photomask 51 in which light intercepting portions 53a and 53b corresponding to the contact hole portions 30 and the transmitting region 31 were disposed as shown in Fig. 18, the contact hole portions 30 and the transmitting region 31 were uniformly exposed at a low illuminance as shown in Fig. 17B. In the first photomask 51, the region other than the light intercepting portions 53a and 53b is a light transmitting portion 52a. It is desirable that the exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed with an exposure amount of 40 mj. In the plan view of Fig. 18, the light intercepting portions 53a and 53b are hatched.

Then, by using a second photomask 54 in which light transmitting portions 52c were disposed so as not to be present in the contact hole portions 30 and the transmitting region 31 as circular regions as shown in Fig. 19, exposure was uniformly performed at a high illuminance as shown in Fig. 17C. In the

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second photomask 54, the region other than the light transmitting portions 52c is a light intercepting portion 53c. It is desirable that the exposure amount at this time is 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj using the second photomask 54 in which the area of the light transmitting portions 52c was 30%. At this time, the area of the circular or polygonal light transmitting portions 52c of the second photomask 54 was 30% of the area of the reflecting electrode and the light transmitting portions 52c were randomly disposed so that the center-to-center distances between adjoining light transmitting portions 52c were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ . Moreover, at this time, the first and the second photomasks 51 and 54 were structured so as to intercept the signal input terminal portion 27 from light as well as the contact hole portions. In the plan view of Fig. 19, the light intercepting portion 53c is hatched.

Then, as shown in Fig. 17D, by performing development with a developing solution TMAH (tetramethylammoniumhydrooxide) manufactured by Tokyo Ohka Kogyo Co., Ltd., the resin in the exposed part (the contact hole portions, the transmitting region and the signal input terminal portion) was completely removed, approximately 40%, with respect to the initial film thickness, of the resin in the part exposed at a low illuminance was left, and approximately 80%,

with respect to the initial film thickness, of the resin in the unexposed part was left.

Then, as shown in Fig. 17E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

The succeeding process is similar to that of the above-described Embodiments 1 to 6. As shown in Fig. 17F, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the substrate 49 having the reflecting region comprising the reflecting electrode 10 having smooth and high-density asperities, and the transmitting region 31 comprising the transparent electrode 37 was formed. In the reflecting electrode on the substrate 49, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoproceses of the photosensitive resin can be reduced, so that the cost necessary for the manufacture of the reflecting plate can be reduced.

Lastly, the substrate 49 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, a phase difference plate and a polarizing plate are bonded to the color filter substrate and

a backlight is set on the back surface of the substrate 49 to complete the transmissive/reflective type liquid crystal display apparatus according to this embodiment.

(Embodiment 8)

A manufacturing process of the substrate 49 of a transmissive/reflective type liquid crystal display apparatus according to Embodiment 8 of the invention will be described with reference to Figs. 20A to 20F.

The substrate of the transmissive/reflective type liquid crystal display apparatus according to this embodiment is the same as the substrate 49 shown in Fig. 15 but is formed by a different manufacturing method. The manufacturing method will be described with reference to the cross-sectional views shown in Figs. 20A to 20F.

First, as shown in Fig. 20A, the positive photosensitive resin 9 (the name of the product: OFPR-800 manufactured by Tokyo Ohka Kogyo Co., Ltd.) is applied to the glass substrate 1 in a thickness of 1 to 5  $\mu\text{m}$ . In this embodiment, the resin 9 was applied in a thickness of 3  $\mu\text{m}$ .

Then, by using the first photomask 43 in which the area of the light intercepting portions 42a was in a range of from 20% to 40% as circular regions as shown in Fig. 10, exposure was uniformly performed at a low illuminance as shown in Fig. 20B. It is desirable that the exposure amount at this time is 20 mj to 100 mj. In this embodiment, exposure was performed

with an exposure amount of 40 mj using the first photomask 43 in which the area of the light intercepting portions 42a was 30%. At this time, the circular or polygonal light intercepting portions 42a of the first photomask 43 were randomly disposed so that the center-to-center distances between adjoining light intercepting portions 42a were in a range of from 5  $\mu\text{m}$  to 50  $\mu\text{m}$ , preferably, 10  $\mu\text{m}$  to 20  $\mu\text{m}$ .

Then, by using a second photomask 55 in which light transmitting portions 52d and 52e corresponding to the contact hole portions 30 and the transmitting region 31 were opened as shown in Fig. 21, the contact hole portions 30 and the transmitting region 31 were uniformly exposed at a high illuminance as shown in Fig. 20C. In the second photomask 55, the region other than the light transmitting portions 52d and 52e is a light intercepting portion 53d. At this time, the second photomask 55 had a light transmitting portion with respect to the signal input terminal portion 27, and the terminal portion 27 was exposed at a high illuminance simultaneously with the exposure of the contact holes and the transmitting portion. It is desirable that the exposure amount at this time is 160 mj to 500 mj. In this embodiment, exposure was performed with an exposure amount of 240 mj. In the plan view of Fig. 21, the light intercepting portion 53d is hatched.

Then, as shown in Fig. 20D, by performing development with a developing solution TMAH

(tetramethylammoniumhydrooxide) manufactured by Tokyo Ohka Kogyo Co., Ltd., the resin in the exposed part (the contact hole portions, the transmitting region and the signal input terminal portion) was completely removed, approximately 40%, with respect to the initial film thickness, of the resin in the part exposed at a low illuminance was left, and approximately 80%, with respect to the initial film thickness, of the resin in the unexposed part was left.

Then, as shown in Fig. 20E, by performing a heat treatment at 200°C for 60 minutes, the resin of the above-described condition was deformed into smooth asperities.

The succeeding process is similar to that of the above-described Embodiments 1 to 7. As shown in Fig. 20F, an Al thin film was formed as the reflecting electrode 10 on the substrate 1, and patterning was performed so that one reflecting electrode 10 corresponds to one transistor.

By the above-described process, the substrate 49 was formed that had the reflecting region comprising the reflecting electrode 10 having smooth and high-density asperities, and the transmitting region 31 comprising the transparent electrode 37. In the reflecting electrode on the substrate 49, the area of the flat part is reduced, so that ideal reflection characteristics with a small regular reflection component can be realized. Moreover, the number of photoprocesses of the photosensitive resin can be reduced, so that the cost necessary

for the manufacture of the reflecting plate can be reduced.

Lastly, the substrate 49 and a color filter substrate for supporting a transparent electrode are bonded together with a spacer therebetween in a manner similar to that of the prior art, liquid crystal is filled, and a phase difference plate and a polarizing plate are bonded to the color filter substrate to complete the transmissive/reflective type liquid crystal display apparatus according to this embodiment.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and the range of equivalency of the claims are therefore intended to be embraced therein.